Local Search Heuristics for Cost Reduction in WDM Bidirectional Rings

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Abstract

In this note *Local Search* heuristics are proposed for the problem of minimizing the number of expensive Add-Drop Multiplexers in a SONET or SDH optical network ring, while respecting the constraints given by the overall number of fibers and the number of wavelengths that can carry separate information on a fiber.

1 Introduction

Due to dramatic advances in optical communications, such as all-optical amplifiers and Wavelength Division Multiplexing (WDM), optical networks provide a very high capacity communication channel. Unfortunately, competitiveness of optical networks is undermined by the high cost of equipment.

Optical netorks usually come in the form of uni- or bidirectional rings, interconnected via hubs to form a hierarchy of rings, as shown in Fig. 1. As many densely packed signals with different wavelengths are carried along a single fiber, a node must be able to split the incoming signal into its components, process them and meld individual wavelengths into the outgoing fiber. Every wavelength can be treated as a sequence of data packets; if we can be sure that all data packets originating from a given node or addressed to that node will be inserted on a fixed subset of wavelengths, then processing will only occur for them, while all other wavelengths, whose packets are of no interest for the node, need only be relayed from the incoming fiber to the outgoing fiber. See, for example, Fig. 2, where only three wavelengths contain packets of interest for the node, while all others are simply sent out.

The key component for processing data packets is called *Add-Drop Multiplexer* (ADM); in fact, its main purpose is to extract (drop) incoming packets from the optical stream and to insert (add) outgoing packets in vacant slots of the stream. In order to work properly, ADMs must be tightly synchronized and fast; therefore they are quite expensive, and they represent a significant fraction of the network cost.

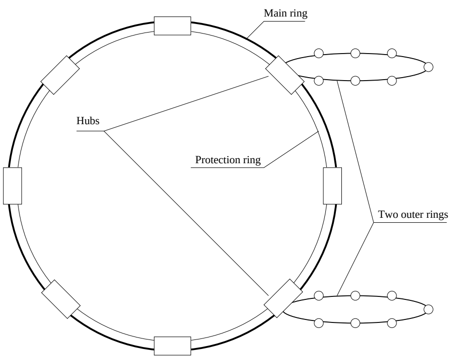

Figure 1: a SONET/SDH hierarchy of rings

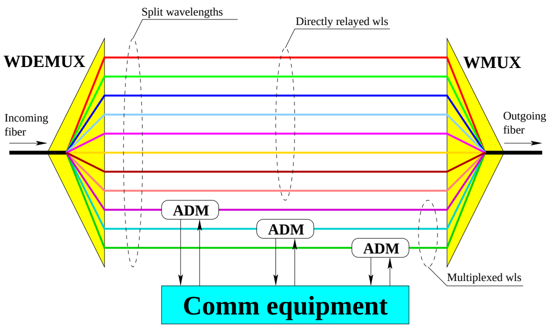

Figure 2: structure of a node in a WDM SONET/SDH ring

2 Problem Statement

Let $\mathcal{R}_n$ be a bidirectional ring with n nodes, numbered from 1 to n. We are given an integer *traffic demand matrix* $T = (t_{ij}) \in \mathcal{M}_{n\times n}(\mathbb{N})$ meaning that the required (directed) traffic from node i to node j is $t_{ij} \in \mathbb{N}$ packets per time unit. The optical fiber can carry m different wavelengths, transporting g packets per time unit each. Note that all traffic data are expressed in the base traffic unit of one packet per time unit.

Given nodes i and j, $1 \leq i, j \leq n$, we define a *virtual connection* from node i to node j to be the periodic transmission of a packet from node i to node j, with the period of one time unit. If the traffic requirement from i to j is t_{ij}, we say that we must establish t_{ij} virtual connections from node i to node j. The problem of assigning multiple virtual connections to a wavelength in an admissible way is known in the literature as *traffic grooming*, and g itself is called the *grooming factor* of the ring.

In other words, to establish a virtual connection we must assign it to a wavelength; a set of virtual connections is *admissible* if for every physical link no more than g virtual connections crossing it are assigned to the same wavelength. Our purpose is to reduce the overall number of ADMs in the ring by properly assigning wavelengths to virtual connections in an admissible way.

3 Previous Work

Previous work in the area mainly focused on unidirectional rings, so that no routing choices had to be performed and every virtual connection only had one possible path from source to destination, and various combinatorial greedy algorithms have been proposed [3, 4, 6]. For example, [4] suggests some techniques for different kinds of traffic matrices, notably the egress-node case where all traffic is directed towards a single hub node, the uniform all-to-all case and a more general distance dependent traffic. Two types of algorithms are presented. Some algorithms attempt to maximize the number of nodes requiring just one ADM, then those requiring two and so forth. Others try to efficiently pack the wavelengths by dividing nodes into groups and assigning to different wavelengths intra-group traffic.

When considering bidirectional (undirected) rings two possible paths can be set up for a virtual connection and therefore, as we add one degree of freedom to the system, a better solution can be hopefully found. For example, [5] proposes a heuristic based on Eulerian trail decomposition of the set of virtual connections; however, the paper only considers a wavelength assignment and routing problem with no grooming, i.e. where two virtual connections crossing the same link must be assigned to different wavelengths, and no time division multiplexing is required.

4 Our Contribution (Work in Progress)

Our research group is developing two strategies. On one side, we want to extend [5] to the grooming case where up to $g > 1$ connections can cross the same link on the same wavelength.

Moreover, we are applying local search techniques, in particular prohibition-based algorithms, such as Fixed Tabu Search and Reactive Local Search (see [1] for a classification), in order to improve the results of the above mentioned techniques.

Some preliminary results are shown in Fig. 3, where we considered a unidirectional ring and a traffic demand equal to 1 for each couple of different nodes (details are given in [2]):

$$t_{ij} = \begin{cases} 1 & i \neq j \\ 0 & i = j \end{cases} \qquad \Rightarrow \qquad T = \begin{pmatrix} 0 & 1 & \dots & 1 \\ 1 & 0 & \dots & 1 \\ \vdots & \vdots & \ddots & \vdots \\ 1 & 1 & \dots & 0 \end{pmatrix}.$$

In Fig. 3 we plot the number of ADMs required for establishing one virtual connection per couple of nodes, against the number of nodes in the ring. Two cases have been considered: $g = 4$ (four periodic time slots per wavelength) and $g = 16$. We compared the most efficient algorithm found in [4] with an implementation of Reactive Local Search with a prohibition mechanism preventing the system from undoing a move within a prohibition period T, where T depends on the behavior of the system.

References

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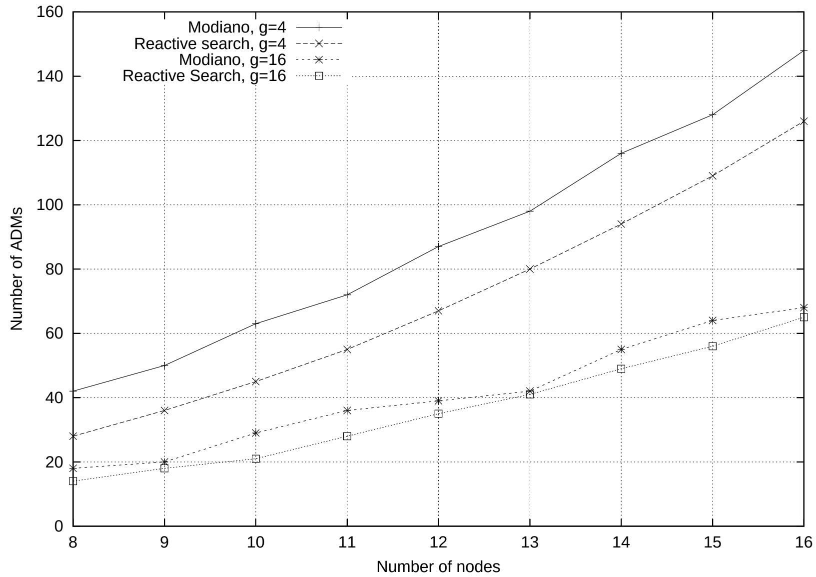

Figure 3: comparison between RLS and Modiano

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